A Classically Scale Invariant Model of Inflation

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1405.3987 by K.K, Antonio Racioppi, Martti Raidal

Goal

- Concrete realisation of ‘Coleman-Weinberg’ inflation in a classically scale-invariant model
- Do it without increasing the gauge group, unlike
  Linde, 1982; Albrect & Steinhardt, 1982; Gonzales-Diaz, 1986; Langbain et al., hep-ph/9310335; Yokoyama, 1999; Rehman, Shafi & Wickman, 0810.3625; Barenboim, Chun & Lee, 1309.1695

3 Tensor-to-Scalar Ratio from BICEP2

BICEP2 measured the tensor-to-scalar ratio

$$r = 0.20^{+0.07}_{-0.05}$$

$r = 0$ disfavoured at 7σ BICEP2 Collaboration, 1403.3985

In moderate tension with the Planck result

$$r < 0.11$$

Planck Collaboration, 1303.5082

4 Confirmations of Inflation

- Almost scale-invariant density perturbations
- Adiabatic initial conditions
- Nearly Gaussian fluctuations
- Spatial flatness
- Tensor perturbations from gravity waves

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- Adiabatic initial conditions ✓
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- Spatial flatness ✓
- Tensor perturbations from gravity waves ✓

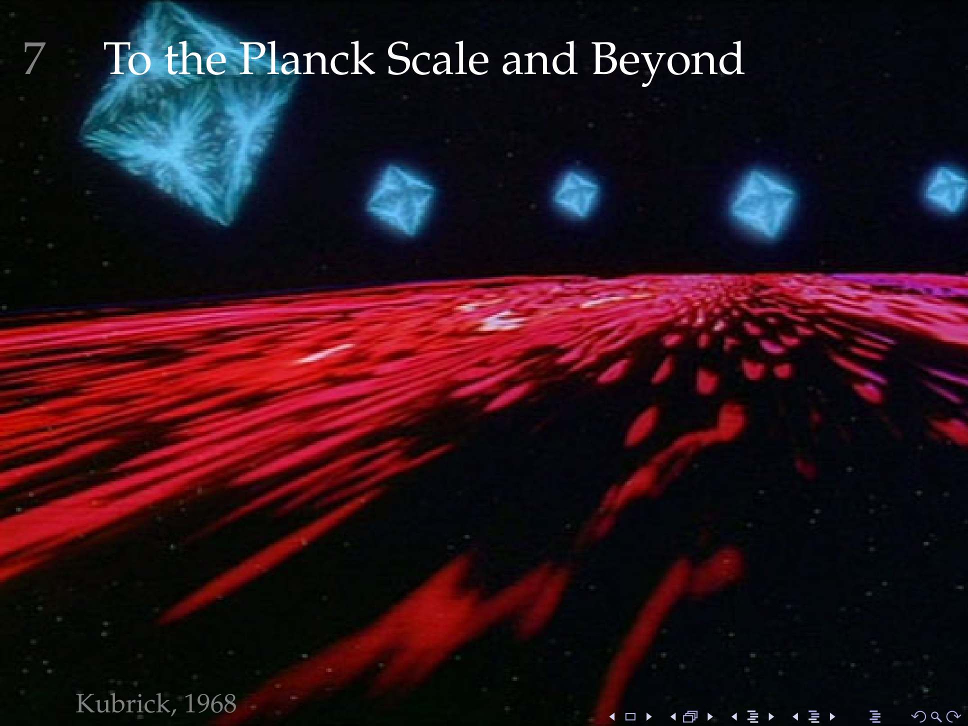
6 To the Planck Scale and Beyond

Large r implies $\dfrac{\phi}{M_P} \gtrsim 1 \ldots 10$ Antusch & Nolde, 1404.1821
Standard Wilsonian expansion

$$V = V_{\rm ren} + \sum_{n=5}^{\infty} c_n \frac{\phi^n}{M_P^{n-4}}$$

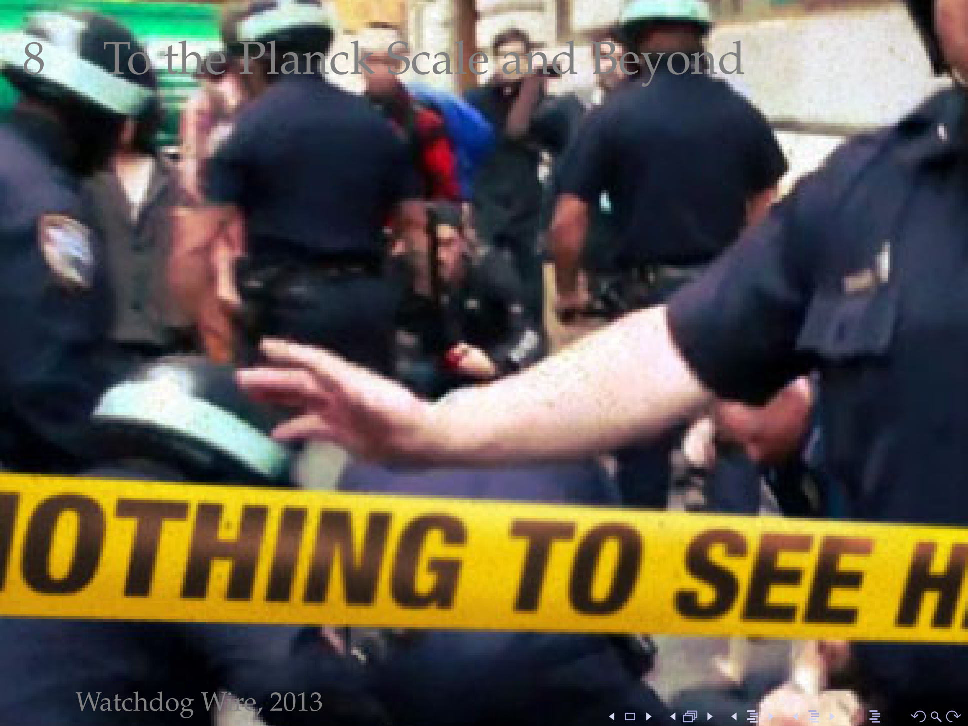
blows up and ruins inflation!

7 To the Planck Scale and Beyond



Kubrick, 1968

To the Planck Scale and Beyond



Watchdog Wire, 2013

9 Classical Scale-Invariance

- No explicit mass scales – no mass terms
- Broken by *logarithmically* running couplings

10 ϕ^4 Potential with Quantum Corrections

ϕ^4 potential with the cosmological constant term Λ^4

$$V = \Lambda^4 + \frac{1}{4}\lambda_\phi \phi^4$$

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ϕ^4 potential with the cosmological constant term Λ^4

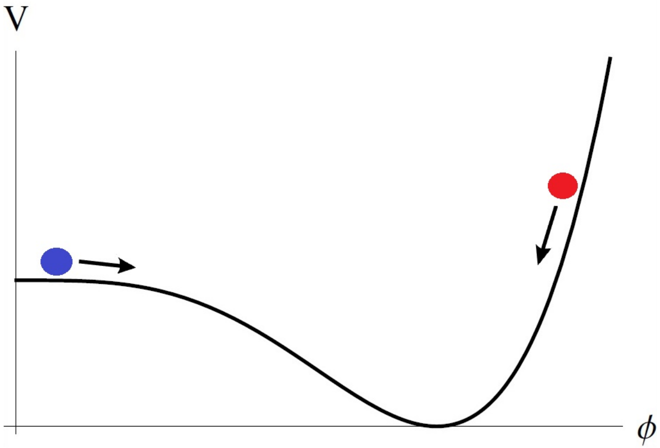
$$V = \Lambda^4 + \frac{1}{4}\lambda_\phi \phi^4 = \Lambda^4 + \frac{1}{4}\lambda_\phi(\phi)\phi^4,$$

where

$$\lambda_\phi(\phi) = \beta_{\lambda_\phi} \ln\left|\frac{\phi}{\phi_0}\right|$$

$$v_\phi = \frac{\phi_0}{\sqrt[4]{e}}, \quad \Lambda = \phi_0 \sqrt[4]{\frac{\beta_{\lambda_\phi}}{16e}}$$

ϕ^4 Potential with Quantum Corrections



- Small-field hilltop inflation
- Large-field chaotic inflation

12 Full Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{2}\partial_\mu\phi\partial^\mu\phi + \frac{1}{2}\partial_\mu\eta\partial^\mu\eta + \mathcal{L}_Y - V,$$

$$\mathcal{L}_Y = Y_N^{ij}\bar{L}_i i\sigma_2 H^* N_j + \text{h.c.} + Y_\phi^{ij}\bar{N}_i^c N_j\phi$$
$$+ Y_\eta^{ij}\bar{N}_i^c N_j\eta,$$

$$V = \Lambda^4 + \frac{1}{2}\lambda_{h\phi}|H|^2\phi^2 + \frac{1}{2}\lambda_{h\eta}|H|^2\eta^2$$
$$+ \frac{\lambda_\phi}{4}\phi^4 + \frac{\lambda_{\phi\eta}}{4}\eta^2\phi^2 + \frac{\lambda_\eta}{4}\eta^4$$

- Real scalars ϕ and η
- Three right-handed neutrinos N_i

13 Effective Potential in Direction of ϕ

- Higgs portal couplings have to be tiny – avoid big corrections to Higgs mass
- Negligible contributions also from N_i

$$V_{\text{eff}} = \Lambda^4 + \frac{\lambda_\phi(\mu)\phi^4}{4} + \frac{\lambda_{\phi\eta}^2}{256\pi^2}\left(\ln\frac{\lambda_{\phi\eta}\phi^2}{2\mu^2} - \frac{3}{2}\right)\phi^4$$

$$\beta_{\lambda_\phi} \propto \lambda_{\phi\eta}^2 \approx \text{const}$$

14 Effective Potential in Direction of ϕ

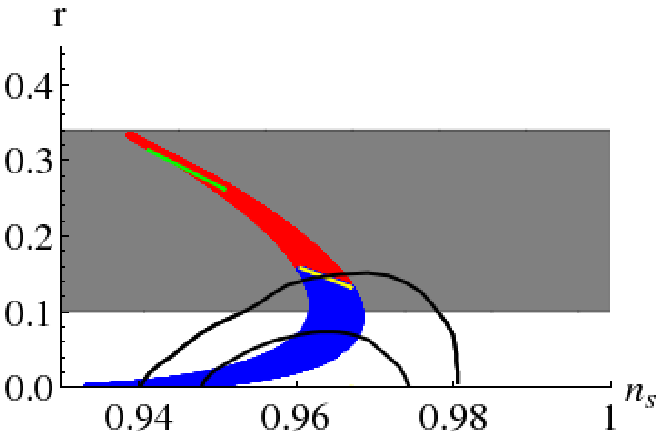
- After a couple lines of algebra,

$$V_{\text{eff}} = \Lambda^4 + \frac{\lambda_{\phi\eta}^2 \ln \frac{\phi^2}{\phi_0^2}}{256\pi^2}\phi^4$$

- η gets a mass via portal coupling as

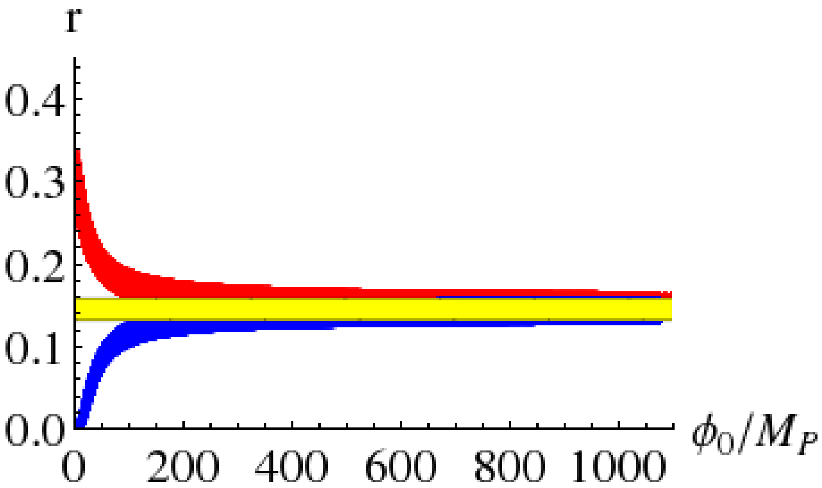
$$m_\eta = \sqrt{\frac{\lambda_{\phi\eta}}{2}} v_\phi$$

Predictions on the r vs. n_s Plane

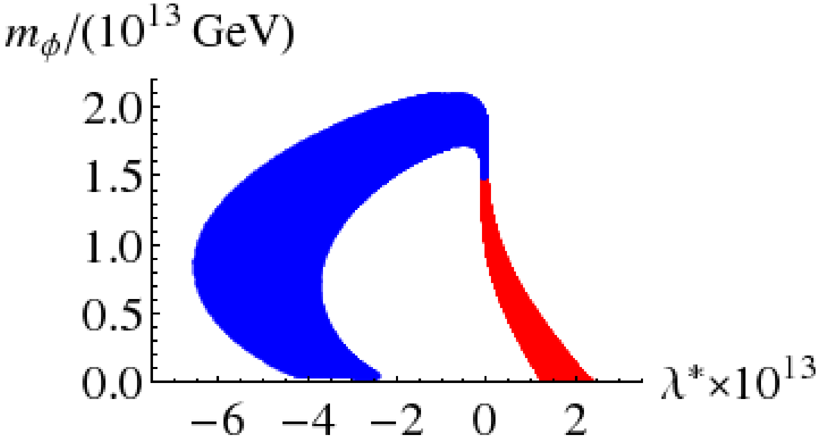


- Small-field hilltop inflation
- Large-field chaotic inflation
- $V = \frac{m^2}{2}\phi^2$ potential
- $V = \lambda\phi^4$ potential

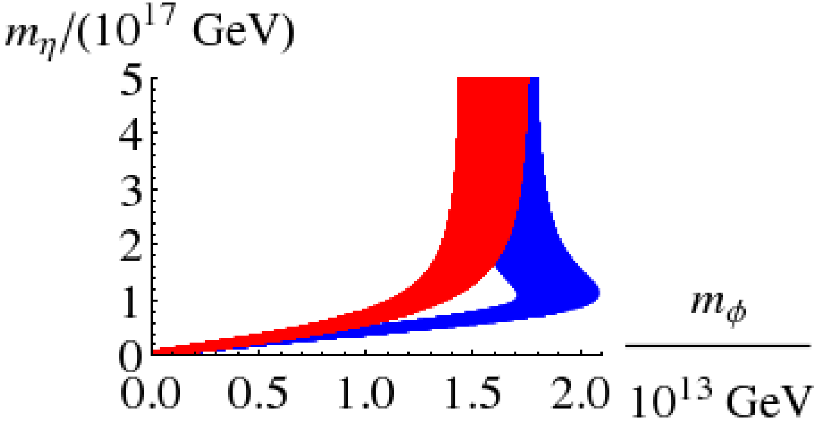
r vs. ϕ_0



Inflaton mass vs. Self-Coupling



Mass of η vs. Inflaton mass



- m_η > inflation scale $\sim 10^{16}$ GeV
- During inflation, $\eta = 0$ and is decoupled

Conclusions

- Single-field ϕ slow-roll inflation with 1-loop effective potential
- Minimal extension of the SM – gauge group not extended
- With classical scale invariance, we need another scalar η to give ϕ a VEV
- Both chaotic and hilltop inflation possible
- Prediction for r the same as for ϕ^2-inflation for large inflaton VEV